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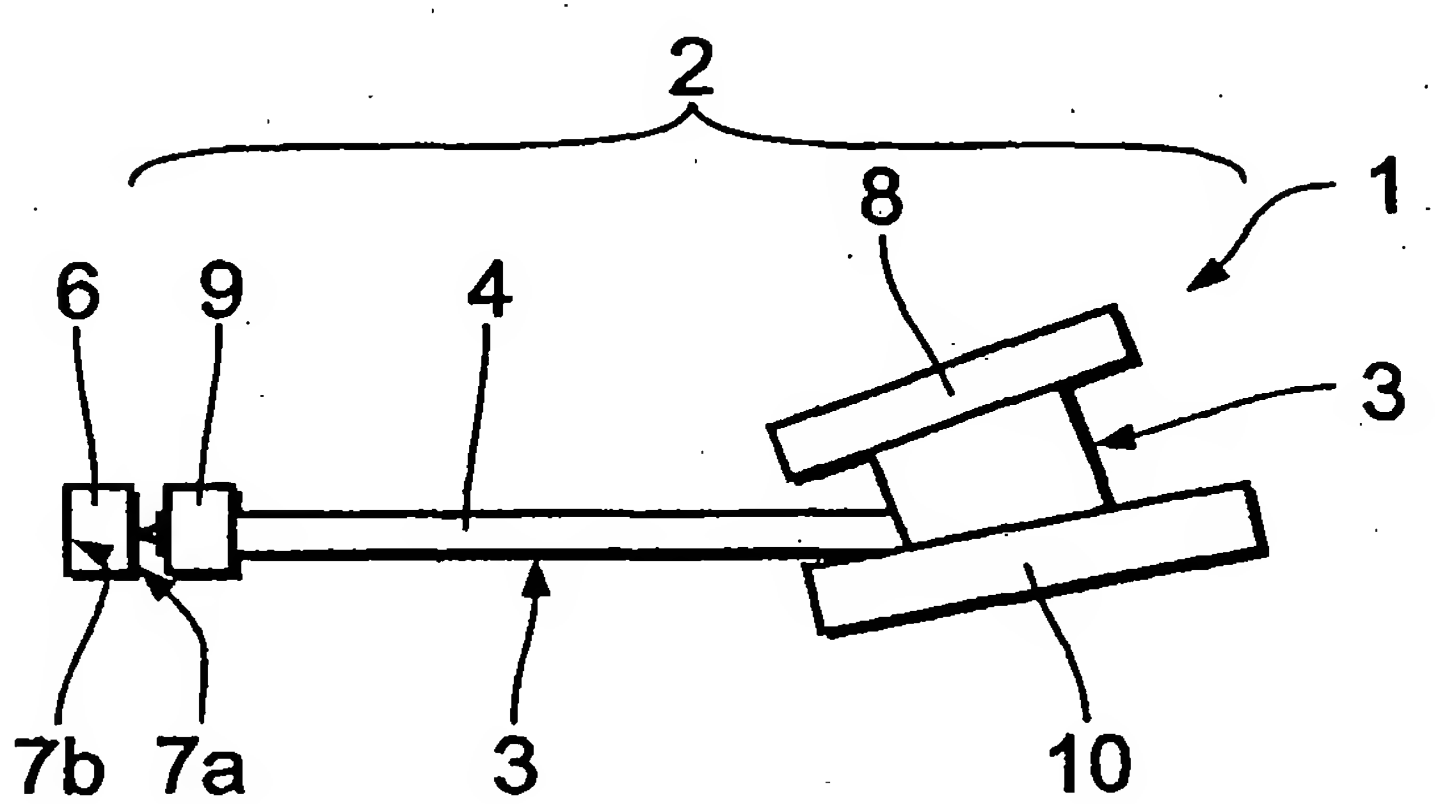
(54) Title: LASER CAVITY WITH VARIABLE DISPERSION ELEMENT



(57) Abstract: The invention relates to a method of tuning a laser, comprising the steps of: providing a laser beam (4) in an external cavity (2) having a dispersion element (10) for selecting at least one mode of the laser, varying the wavelength characteristic of the dispersion element (10).

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LASER CAVITY WITH VARIABLE DISPERSION ELEMENT

BACKGROUND OF THE INVENTION

The present invention relates to tuning a laser with an external laser cavity.

In the optical communication industry there is a need for testing e.g. optical components and amplifiers with lasers at different wavelengths. For this purpose, various types of laser cavities are known.

Tunable lasers are described e.g. as the so-called Littman geometry in "Liu and Littman, Novel geometry for single-mode scanning of tunable lasers, Optical Society of America, 1981", or as the so-called Littrow geometry in EP 0 952 643 A2. Bragg-reflector type cavities are shown e.g. "A. Nahata et al., Widely Tunable Semiconductor Laser Using Dynamic Holographically-Defined Distributed Bragg Reflector, 2000 IEEE". The teaching of those documents shall be incorporated herein by reference.

SUMMARY OF THE INVENTION

It is an object of the invention to provide improved tuning of a laser. The object is solved by the independent claims.

For the sake of clarity, the terms 'vary', 'variation', 'variable', etc. as used herein are to be interpreted as an intended changing of a property.

An advantage of a preferred embodiment of the present invention is the possibility of (e.g. non-mechanically) performing a compensation for deviations, e.g. geometrical or optical deviations, in the laser cavity setup to provide mode hop free tuning of the laser. Furthermore, it is possible to (e.g. non-mechanically) tune the laser according to a preferred embodiment of the invention.

In a preferred embodiment the variation of the wavelength characteristic of the dispersion element is done by using a periodic structure as the dispersion element and varying the wavelength characteristic of the dispersion element by varying the periodicity of the periodic structure. The variation of the periodicity of the periodic structure can be done by varying the length of a substrate for the periodic structure.

Alternatively or additionally it can be done by using as a material for the substrate any material having a voltage-, magnetism-, pressure-, humidity-, light- and/or temperature-sensitive length, and varying the length of the material by varying the voltage, magnetism, pressure, humidity, light and/or temperature applied to the material.

Alternatively or additionally, it can also be done by using a chirped Bragg grating as the dispersion element and varying the wavelength characteristic of the dispersion element by moving the chirped Bragg grating. A chirped Bragg grating is a grating in which the period of the grating varies with position in the

grating. The moving of the chirped Bragg grating can be performed by at least one of the following: translating the chirped Bragg grating, rotating the chirped Bragg grating.

Moreover, alternatively or additionally it is possible to vary the periodicity of the periodic structure by using variable electromagnetic or acoustic waves creating a periodic structure or acting on a periodic structure. The variability of the waves comprising at least one of the following: varying their wavelength, varying the angle of incidence on the variable periodic structure.

Due to deviations of real geometry with respect to perfect configuration and/or chromatic dispersion of the necessary optical components, in inventive embodiments using a geometry for continuous tenability, e.g. a Littman or Littrow geometry, a pivot point can generally only be found for a limited wavelength range. According to the present invention, corrections of these deviations or of the dispersion are made by varying the wavelength characteristic of the dispersion element in order to provide mode hop free tuning in an enlarged tuning range of the cavity.

In preferred embodiments of the inventive apparatus to perform the inventive method the shifting or rotation of the chirped Bragg grating relative to the laser beam can be driven by a piezo-electric translocating element which can precisely shift or rotate the grating.

Other preferred embodiments are shown by the dependent claims.

It is clear that the invention can be partly embodied or supported by one or more suitable software programs, which can be stored on or otherwise provided by any kind of data carrier, and which might be executed in or by any suitable data processing unit.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and many of the attendant advantages of the present invention will be readily appreciated and become better understood by reference to the following detailed description when considering in connection with the accompanied drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present invention. Features that are substantially or functionally equal or similar will be referred to with the same reference sign(s).

Fig. 1-3 show schematic views of embodiments of the apparatus of the present invention;

Fig. 4 shows an example of a variable grating in greater detail;

Fig. 5-7 show schematic views of further embodiments of the apparatus of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a schematic view of a first embodiment 1 of the apparatus of the present invention. Embodiment 1 comprises an external cavity 2 in which laser light provided by an integrated laser diode 6 as an active medium can resonate to provide a laser beam 4. One side 7b of the laser diode 6 serves as a cavity end element. Beam 4 travels in the cavity 2 along a path 3 between the cavity end element 7b and a tuning element 8, both providing a high-reflective mirror. Beam 4 is focused by a lens 9 in the path 3 on the front side 7a of the laser diode 6.

Embodiment 1 further comprises a dispersion element 10 introduced in the path 3 of the beam 4 for selecting at least one (preferably a longitudinal) mode of the laser. The dispersion element 10 comprises a variable grating 12 (see figure 4).

Embodiment 1 is configured in a Littman-type configuration. Therefore, the

tuning element 8 can be rotated by an actuator (not shown) about a (not shown) pivot axis to tune the laser. The pivot axis is theoretically defined by the intersection of the optical surface planes of the cavity end element 7b of the laser diode 6, the dispersion element 10 and the tuning element 8.

The variable grating 12 of the dispersion element 10 can be varied by varying the wavelength characteristic of the grating 12, i.e. by varying the period of the grating 12. For this purpose the grating 12 is mounted on a substrate. Figure 4 shows this in greater detail.

Figure 4 shows the dispersion element 10 with the substrate 11 and the grating 12. The substrate 11 is a piezo-electric element, which can be influenced by a voltage 14 via connecting lines 16 and 18. Varying the voltage 14 will vary the length 20 of the substrate 11. Consequently, the period 22 of the grating 12 will vary accordingly. This variation of period 22 of the grating 12 can compensate a shift between a real position of the pivot axis and a theoretically by the Littman theory defined position. The variation of the grating period 22 has to be done to such an extent that the compensation is sufficient to provide continuous single-mode tuning within a predetermined tuning range of the tuning element 8.

Alternatively, the tuning itself can be done by the variation of the period 22 of the grating 12. This is also done by varying the voltage 14 and therefore the length of the substrate 11.

Alternatively, the compensation or the tuning can be done by varying the length of the substrate with other measures, e.g. with heat, pressure, light, magnetism, humidity and/or temperature.

Figure 2 shows a second embodiment 100 of the present invention. Embodiment 100 is configured in a Littrow-type configuration. Therefore, the dispersion element 10 serves also as the tuning element. Besides that the

dispersion element 10 can be build up by a piezo-electric element, also. Therefore, in embodiment 100 of Figure 2 the compensation of a shift between a real position of the pivot axis of dispersion element 10 and a theoretically by the Littrow theory defined position and a tuning can both be done by the combined dispersion element 10 comprising a piezo-electric element according to Figure 4.

As an alternative to the piezo-electric element as the dispersion element 10 of embodiment 1 and 100 a variable periodic index structure can be generated in the dispersion element 10 with light or by sound (not shown). E.g. a periodic light structure exposes a material and the generated carrier density yields a periodic index structure or variable acoustic waves generated by a piezo oscillator or an acusto-optic modulator generate a periodic structure (not shown). The variation of such a periodic light or sound structure can be done by a variation of the irradiation wavelength or a variation of the irradiation angle (not shown).

Figure 3 shows a third embodiment 300 of the present invention. In embodiment 300 the cavity 2 is configured in a Bragg reflector configuration. Therefore, a Bragg reflector 302 having a variable periodic structure 304 is used. The Bragg reflector 302 can then be mounted on a piezo electric substrate 306 as shown in more detail in Figure 5. Optionally, it can be etched directly into a piezo-electric substrate (not shown).

Alternatively, as shown in a fourth embodiment 400 according to Figure 6 the Bragg reflector can be periodically diffused material 402 diffused in a piezo-electric element 404. Then by varying the length 20 of the piezo-electric element 404 the period 22 of the Bragg reflector 402 can be varied to tune the laser. Optionally, other materials can be used instead of piezo-electric material.

Figure 7 shows a fifth embodiment 500 of the present invention. Embodiment 500 is configured in a Littman-type configuration. Embodiment 500 uses a

chirped Bragg grating 502 as a dispersion element 10. By moving the dispersion element 10 with a linear motor 504 connected to the dispersion element 10 by a connector 506 the chirped Bragg grating 502 can be moved and by this the above-mentioned compensation or tuning facility of the present invention is provided.

CLAIMS:

1. A method of tuning a laser, comprising the steps of:

providing a laser beam (4) in an external cavity (2) having a dispersion element (10) for selecting at least one mode of the laser,

varying the wavelength characteristic of the dispersion element (10).

2. The method of claim 1, further comprising the steps of:

controlling the variation to provide at least one of the following steps:

avoiding mode hops in a certain wavelength range when tuning the laser, tuning the laser, at least partly compensating a deviation between an actual and a theoretical geometry of the cavity (2) for a continuous tunability.

3. The method of claims 1 or 2, further comprising the steps of:

using a periodic structure (12, 302, 304, 402) as the dispersion element (10),

varying the wavelength characteristic of the dispersion element (10) by varying a periodicity (22) of the periodic structure (12, 302, 304, 402).

4. The method of claim 3, further comprising the step of:

varying the periodicity (22) of the periodic structure (12, 302, 304, 402) by varying a length (20) of a substrate (11, 306, 404) for the periodic structure (12, 302, 304, 402).

5. The method of claim 4, further comprising the step of:

varying the length (20) of the substrate (11, 306, 404) by:

using as a material for the substrate (11, 306, 404) any material having at least one of the following: a voltage-, magnetism-, pressure-, humidity-, light-, temperature-sensitive length, preferably by using as the material a piezo-electric material (11, 306, 404), and

varying the length of the material by varying at least one of the following: the voltage, magnetism, pressure, humidity, light, temperature applied to the material.

6. The method of claims 1 or 2, further comprising the step of:

using a chirped Bragg grating (502) as the dispersion element (10),

varying the wavelength characteristic of the dispersion element (10) by moving the Bragg grating (502).

7. The method of claim 6, further comprising the step of:

moving the Bragg grating (502) by at least one of the following: translating the Bragg grating (502) relative to the laser beam (4), rotating the Bragg grating (502) relative to the laser beam (4).

8. The method of claim 3, further comprising the step of:

varying the periodicity (22) of the periodic structure (12, 302, 304, 402) by using variable waves acting on the periodic structure (12, 302, 304, 402) .

9. The method of claim 8, further comprising the step of:

using variable electromagnetic waves.

10. The method of claim 8, further comprising the step of:

using variable acoustic waves.

11. The method of any one of the claims 8 - 10, further comprising the steps of:

the variability of the waves comprising at least one of the following: varying their wavelength, varying the angle of incidence on the variable periodic structure (12, 302, 304, 402).

12. The method of any one of the claims 1 - 11, further comprising the following steps when using a rotating tuning element (8) in a cavity (2) having an optical path length (3), the cavity (2) being of Littman or Littrow type:

at least approximately evaluating a function which determines the quantity of variation of the optical path length (3) for generating mode or wavelength hop free rotating of the tuning element (8) within a predetermined tuning range of the tuning element (8) as a function of the rotation angle of the tuning element (8), by:

(a) substantially detecting mode or wavelength hops during rotation of the tuning element (8),

(b) rotating the tuning element (8) about a predetermined angle until at least one mode or wavelength hop has substantially occurred,

(c) varying the optical path length (3) by an arbitrary quantity by varying the wavelength characteristic of the dispersion element (10),

(d) rotating back the tuning element (8) about the predetermined angle of step (b),

repeating steps (a) to (d) with increasing or decreasing quantity of variation of step (c) until substantially no mode or wavelength hops during rotation of the tuning element (8) are detected in step (b),

using the quantity of variation of step (c) per rotating angle of step (b) to evaluate an approximation of the function that determines the quantity of variation of the optical path length (3) per rotating angle of the tuning element (8).

13. The method of claim 12, further comprising the step of:

varying the optical path length (3) according to the approximation function before or while rotating the tuning element (8).

14. The method of claim 13, further comprising the steps of:

measuring the quantity of variation of the variation of the optical path length (3),

comparing the measured value with the predetermined value, adjusting the quantity of variation when detecting a difference between the measured value and the predetermined value.

15. The method of any one of the claims 12 - 14, further comprising at least one of the steps of:

modulating the variation of the optical path length (3) of the path (4), modulating the variation of the periodicity (22) of the grating (12).

16. A software program or product, preferably stored on a data carrier, for executing the method of one of the claims 1 to 15 when run on a data processing system such as a computer.

17. An apparatus for tuning a laser, comprising:

an external cavity (2),

a dispersion element (10) for selecting at least one mode of the laser, the dispersion element (10) having a variable wavelength characteristic.

18. The apparatus of claim 17, further comprising:

a control unit adapted for varying the wavelength characteristic of the dispersion element (10) to provide at least one of the following steps:

avoiding mode hops in a certain wavelength range when tuning the laser, tuning the laser, at least partly compensating a deviation between an actual and a theoretical geometry of the cavity (2) for a continuous tunability.

19. The apparatus of claims 17 or 18,

wherein the dispersion element (10) comprises a periodic structure (12, 302, 304, 402), so that the wavelength characteristic of the dispersion element (10) is variable by varying the periodicity of the periodic structure (12, 302, 304, 402).

20. The apparatus of claim 19, further comprising:

a substrate (11, 306, 404) for the periodic structure (12, 302, 304, 402), the substrate (11, 306, 404) having a variable length (20).

21. The apparatus of claim 20,

wherein a material for the substrate (11, 306, 404) comprises any material having at least one of the following: a voltage-, magnetism-, pressure-, humidity-, light-, temperature-sensitive length, and

the apparatus comprises means for varying the length (20) of the material by varying at least one of the following: the voltage, magnetism, pressure, humidity, light, temperature applied to the material.

22. The apparatus of claims 17 or 18,

wherein the dispersion element (10) comprises a chirped Bragg grating

(502), so that the wavelength characteristic of the dispersion element (10) is variable relative to the laser beam (4) by moving the Bragg grating (502).

23. The apparatus of claim 22,

wherein the wavelength characteristic of the chirped Bragg grating (502) is variable relative to the laser beam (4) by at least one of the following: translating the Bragg grating (502) relative to the laser beam (4), rotating the Bragg grating (502) relative to the laser beam (4).

24. The apparatus of claim 19, further comprising:

a piezo-electric translocating element (504) for doing at least one of the following: translating the Bragg grating (502) relative to the laser beam (4), rotating the Bragg grating (502) relative to the laser beam (4).

25. The apparatus of claim 19,

wherein the periodicity (22) of the periodic structure (12, 302, 304, 402) is variable by variable waves acting on the periodic structure (12, 302, 304, 402).

26. The apparatus of claim 25,

wherein the periodicity (22) of the periodic structure (12, 302, 304, 402) is variable by variable electromagnetic waves.

27. The apparatus of claim 25,

wherein the periodicity (22) of the periodic structure (12, 302, 304, 402) is variable by variable acoustic waves.

28. The apparatus of any one of the claims 25 - 27, further comprising:

a varying element for varying the waves by one of the following: varying their wavelength, varying the angle of incidence on the variable periodic structure (12, 302, 304, 402).

29. The apparatus of any one of the claims 17 - 28,

wherein the external cavity (2) is of one of the following types: Littman, Littrow, Bragg-reflector.

30. Dispersion element for use in an optical setup, comprising:

a variable periodic structure (12, 302, 304, 402), so that the wavelength characteristic of the dispersion element (10) is variable by varying the periodicity (22) of the periodic structure (12, 302, 304, 402).

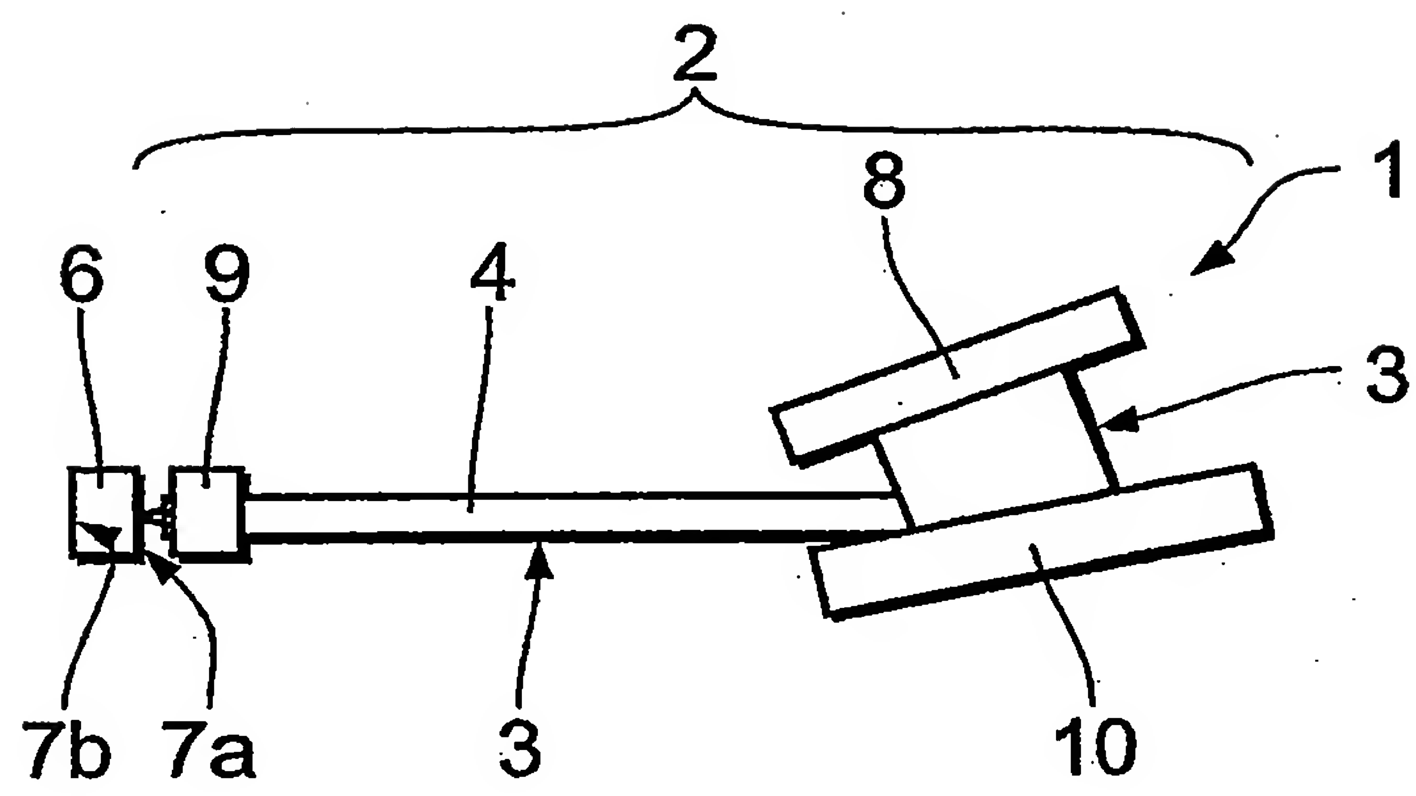

Fig. 1

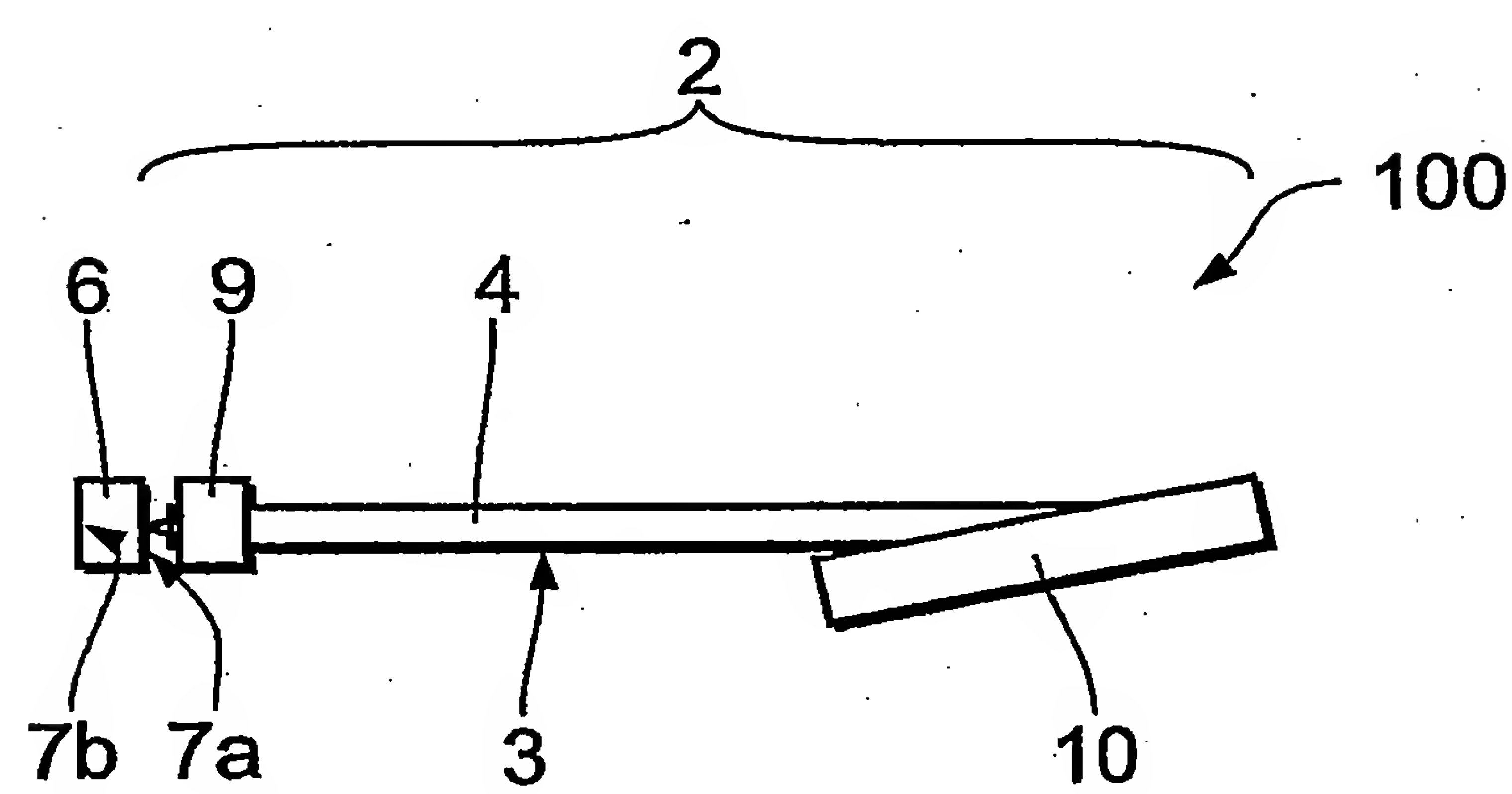

Fig. 2

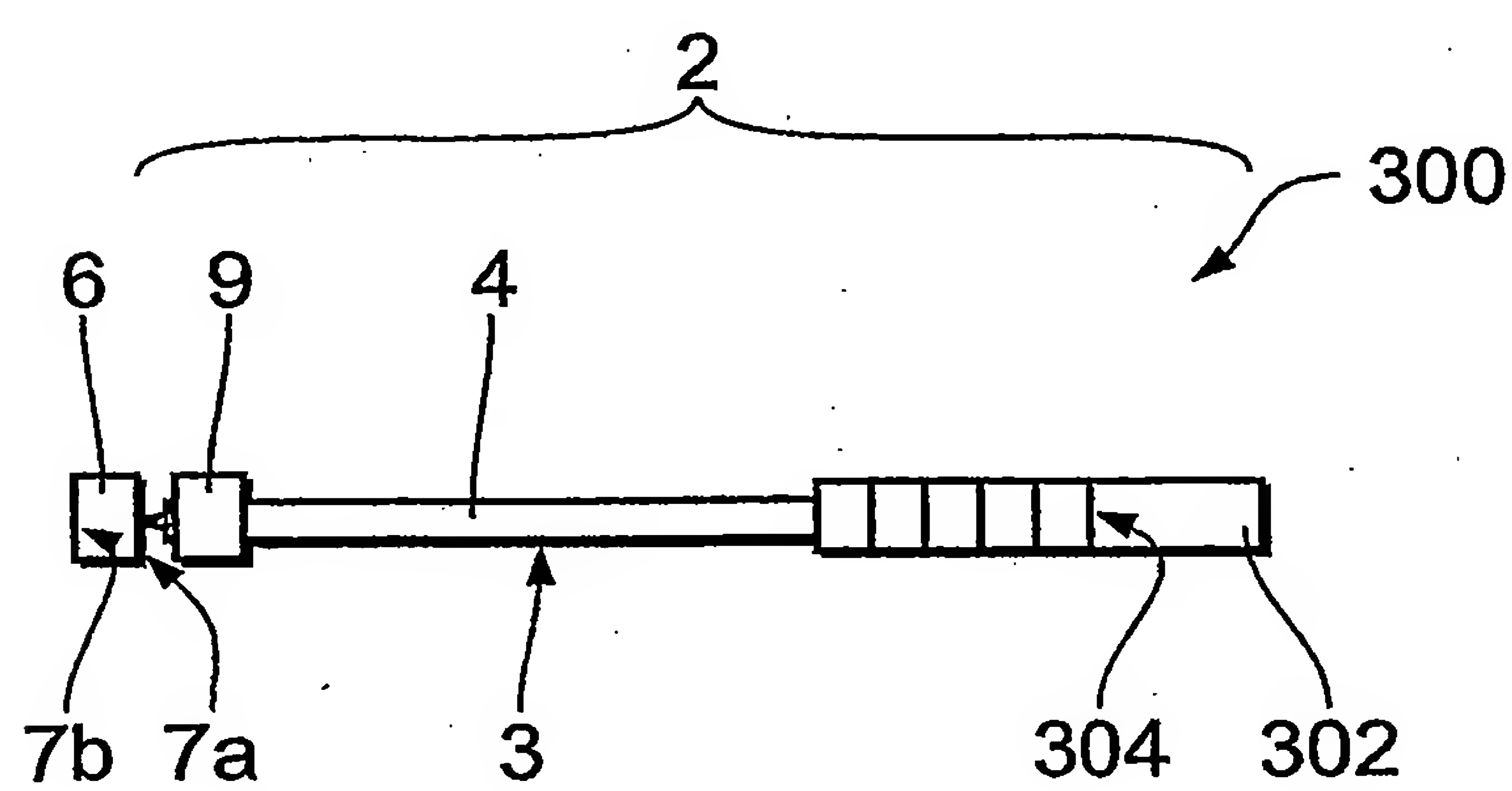

Fig. 3

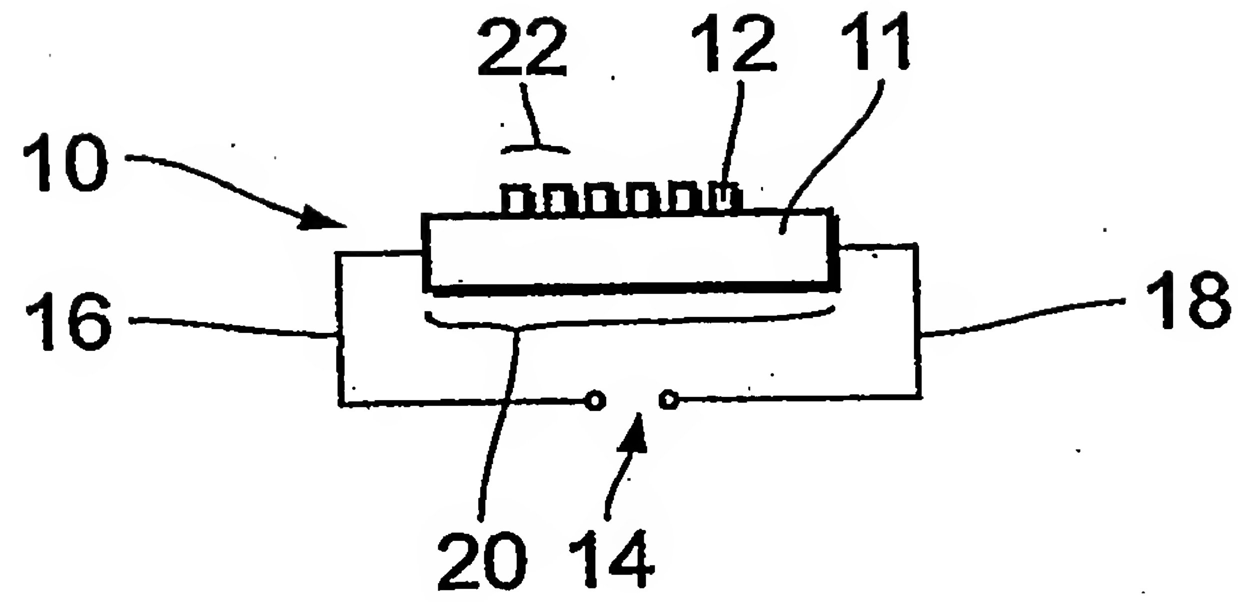

Fig. 4

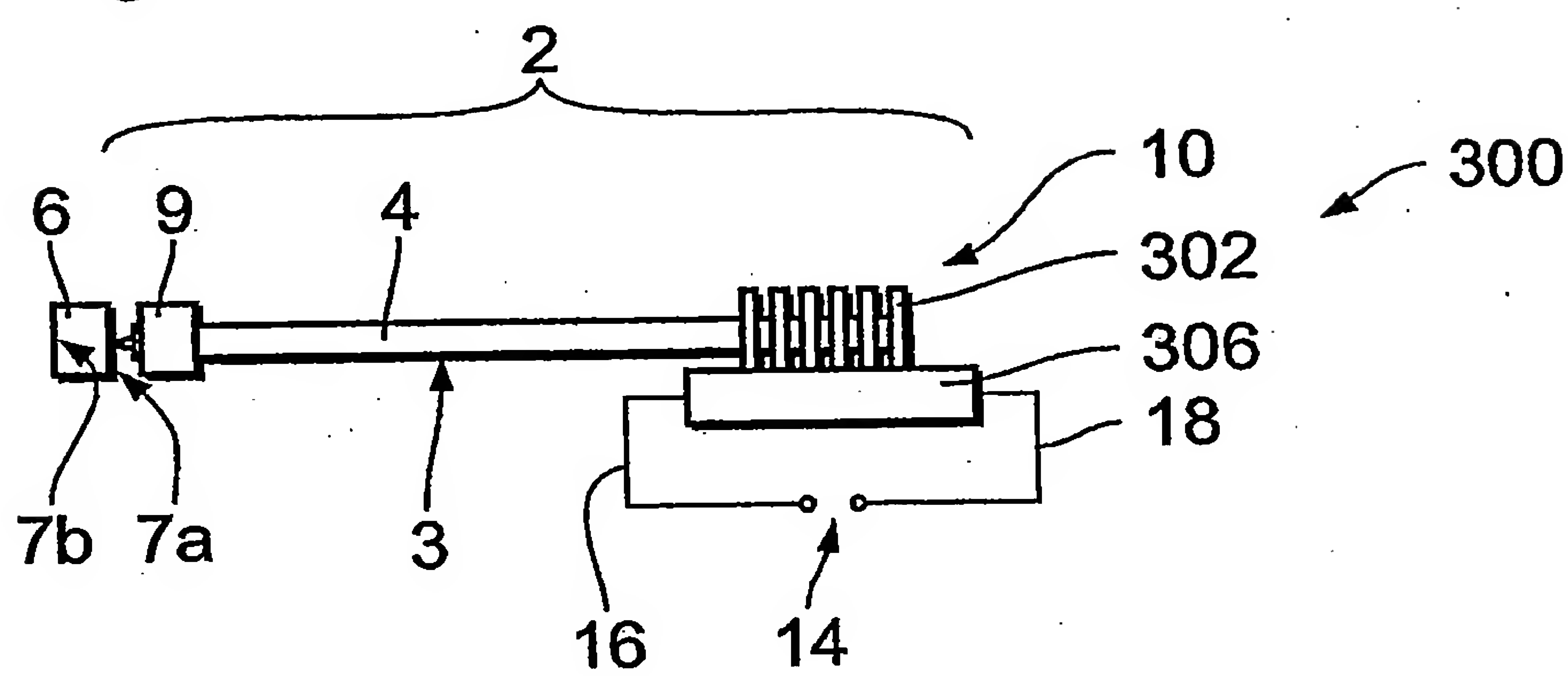

Fig. 5

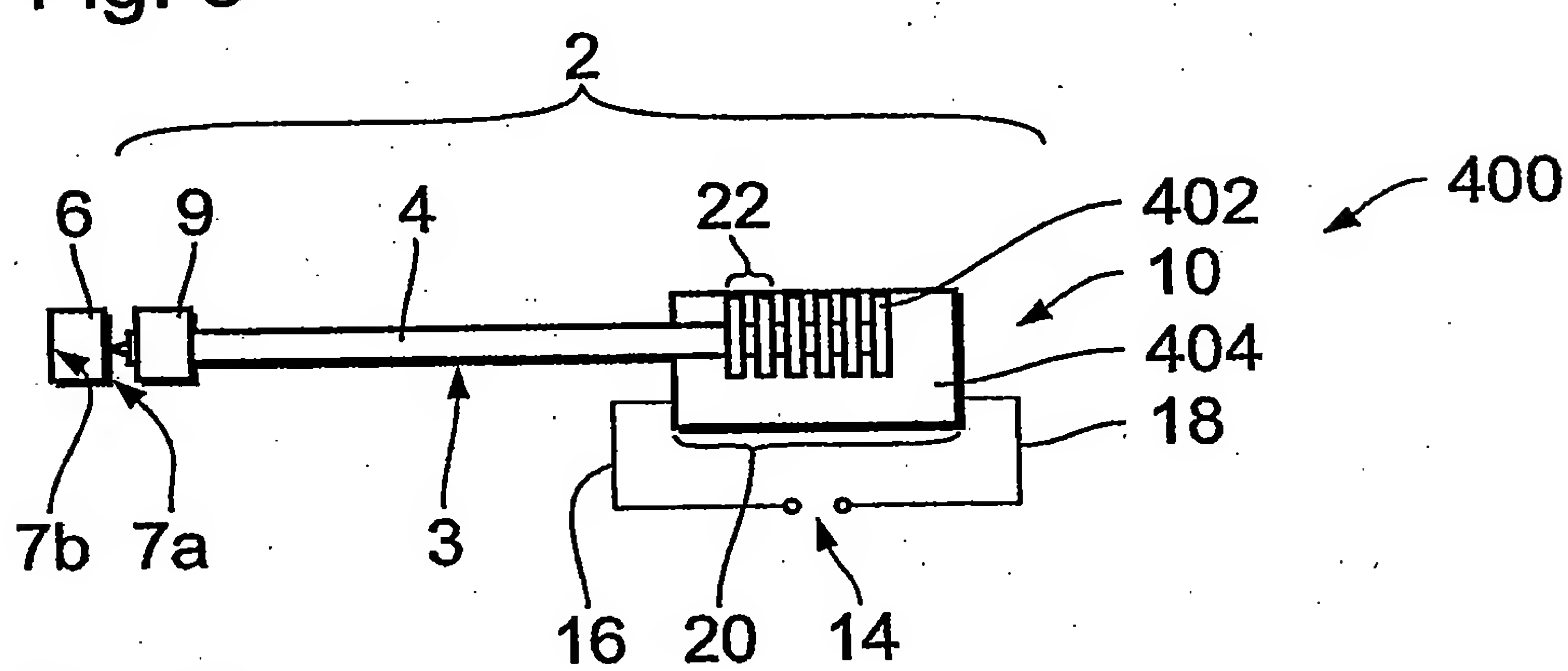

Fig. 6

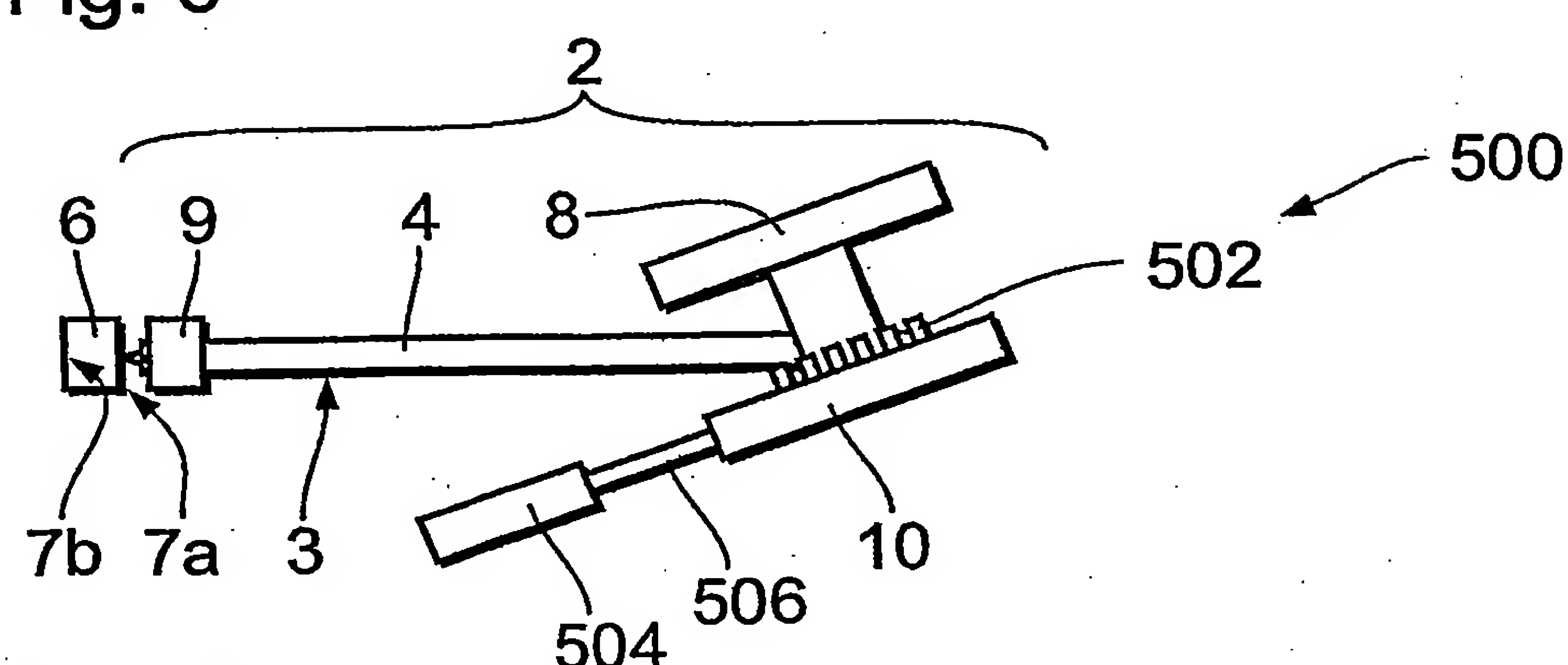

Fig. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 02/05443

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01S3/1055 H01S3/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data, IBM-TDB, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 5 867 512 A (SACHER JOACHIM) 2 February 1999 (1999-02-02) column 6, line 40-65 column 9, line 1-16; figure 2 ---	1-3, 17-19

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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Date of the actual completion of the international search	Date of mailing of the international search report
17 September 2002	27/09/2002

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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